AD-A278 606

REPORT DOCUMENTATION PAGE

Form Approved
OMB No 0704-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	July 1990	Technical May 1990 - July 1990

4. TITLE AND SUBTITLE
A Simplified Stochastic Munition Lethality and Target Vulnerability Computer Model

5. FUNDING NUMBERS
C

6. AUTHOR(S)
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8. PERFORMING ORGANIZATION REPORT NUMBER
SPC 90-282-7

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Advanced Research Projects Agency (ARPA)
3701 North Fairfax Drive
Arlington, Virginia 22203-1714

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Contract No. DAAA21-88-C-0170

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

A statistical based analysis methodology was investigated as the basis for the development of a simplified, inexpensive to operate, reliable munition lethality assessment model for use on desk-top personal comuters. The model evaluates the effectiveness of warhead blast, fragmentation, and axially oriented kill mechanisms on numerous target vulnerable components. This model has utility in assessing the performance of warheads against all types of air, sea, land, and personnel targets. The advantage to the munition designer of having this analysis tool is the ability to quickly tradeoff critical warhead and delivery system parameters which most affect the lethality of fragmentation warheads, utilizing natural fragmentation, preformed fragmentation, or aimable fragmentation concepts. The performance of traditional axial munition components, such as shaped charge jets, explosively formed penetrators, and kinetic energy projectiles is also modeled.

14. SUBJECT TERMS
lethality and vulnerability modeling, fragmentation, blast, axial penetrators, vulnerable components, desk-top computer, target geometry, munition parameters

15. NUMBER OF PAGES
21

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	Unlimited

NSN 7540-01-280-5500 DTIC QUALITY INSPECTED 3 Standard Form 298 (Rev. 2-89)

SPC 90-282-7

A SIMPLIFIED STOCHASTIC MUNITION LETHALITY AND TARGET VULNERABILITY COMPUTER MODEL

JULY 1990

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CONTENTS

1. BACKGROUND

A statistical based analysis methodology was investigated as the basis for the development of a simplified, inexpensive to operate, reliable munition lethality assessment model for use on desk-top personal computers. This model evaluates the effectiveness of warhead blast, fragmentation, and axially oriented kill mechanisms on numerous target vulnerable components. The advantage to the munition designer of having this analysis tool is the ability to quickly tradeoff critical warhead and delivery system parameters which most affect the lethality of fragmentation warheads, utilizing natural fragmentation, preformed fragmentation, or aimable fragmentation concepts.

State-of-the-art lethality modeling techniques, whether they rely on the assessment of target vulnerable areas, target compartment kill criteria, compartment internal point burst modeling, or finely detailed elegant target shot-line generation, fall short in adequately assessing the lethality contribution of warhead fragmentation. The above mentioned analysis tools are adequate to any desired level of detail for assessing the performance of warhead axial kill mechanisms, such as a shaped charge jet, explosively formed penetrator (EFP), or kinetic energy penetrators, attacking the target over various azimuths and elevations, based on missile or projectile accuracy. However, when a significant kill mechanism of the munition is explosive blast and some form of natural warhead fragmentation, such as discrete or continuous expanding rods, preformed fragmentation, multiple radial shaped charges or EFPs, or aimable case fragmentation, the statistical modeling of the interaction of the fragmentation pattern with the target geometry becomes significantly more complex than what can be handled in a timely manner by existing vulnerability models.

Since warhead fragmentation can be an efficient and effective kill mechanism against relatively soft targets, such as aircraft and lightly armored and unarmored ground targets, developing a straight-forward, computationally quick, probability based modeling tool, which accounts for fragmentation patterns, allows the warhead/munition designer to tradeoff critical warhead parameters in an objective and scientific

manner, to maximize the lethality of the weapon against various classes of targets, prior to making a commitment to build and test actual hardware. Of equal importance is developing a simple, reliable, and inexpensive analysis tool, which can be proliferated and which provides results in a timely manner, to affect design tradeoffs and design optimization during the conceptual design period of development, when greatest flexibility exists.

The warhead lethality methodology developed here as a personal computer based analysis tool considers the importance of reliable tradeoff analysis among parameters affecting fragmentation warheads, in addition to modeling the effects of munition axially oriented and blast kill mechanisms. The significance of being able to provide the munition designer with such a convenient tool cannot be overstated. When seriously considering the tradeoffs among the various system parameters, such as fragment velocity, fragmentation patterns, number of fragments, fragment size and lethality, munition-target closing velocity, attack azimuth and elevation, munition accuracy, and proximity fuze functioning, the designer needs a desk-top tool with which to quickly build target models of interest and then to quickly evaluate a candidate fragmentation munition performance. Such a model, of course, would also allow the modeling of the effectiveness of an axial warhead component and blast effects, since all three mechanisms are often used together in munition systems. This model has demonstrated quick turn-around parametric tradeoff analysis of the many kill mechanisms of missiles, projectiles, or bombs against any conceivable target -- aircraft, surface vessels, ground vehicles, structures, and personnel. Several example calculations are provided.

2. METHODOLOGY DEVELOPMENT

The problem of assessing the lethality of a fragmentation warhead against a specified target can be best described by comparing and contrasting it to the method of assessing the effectiveness of an axial kill mechanism, such as a shaped charge jet, EFP, or kinetic energy penetrator. Using a simplified example, if we were designing a missile warhead for the purpose of killing an airplane, and at one specific attack azimuth and elevation the airplane presented a target area shaped like the 10' by 10' square in Figure 2.1, there are at least three basic munition parameters that must be traded off to assess the missile lethality: 1) the missile aimpoint on the target; 2) the missile accuracy with respect to the aimpoint or its CEP (Circular Error Probability); and 3) the effectiveness of the warhead axial kill mechanism against this aspect of the target. The first two parameters describe the probability of the missile hitting the target, or its P_h. The second describes the probability of the missile killing the target if it is hit, or its $P_{k/h}$. The combined single shot kill probability (SSP_k) of the missile is the product of these two values.

In this example, the aimpoint, for simplicity, will be the center of the presented area of the target, although this is not a rigid requirement for any analysis. The accuracy, or CEP will be 10 feet, meaning that there is a 50% probability that the missile will pass within a circle of radius 10 feet about the intended aimpoint. Circular error is also not a rigid requirement for any analysis, but it is chosen here for simplicity. The axial warhead kill mechanism will be a single EFP of sufficient terminal effects to give a 50% probability of killing the target if it is hit.

The 10 feet CEP describes a binormal probability distribution of missile impact points around the target aimpoint. There is one normal distribution of impact points in the vertical direction, and another in the horizontal direction. Each distribution has the same standard deviation, σ, as defined by the well known relationship shown in Figure 2.1.

To assess the probability of a missile hit on the target, we calculate that 1σ equals approximately 8.5 feet from the aimpoint. Since the

horizontal and vertical dimensions of the target about the aimpoint is ±5 feet, the missile must impact within ±.59σ in order to hit the target. Consulting the normal probability density function, the probability of having a value

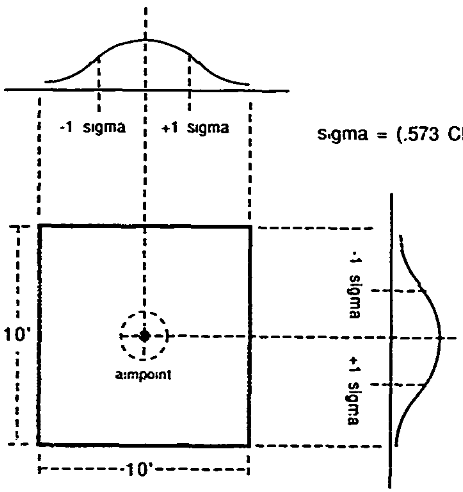


Figure 2.1 - Binormal Distribution of Impact Points

between -.59σ and +.59σ is approximately .44 or 44%. Therefore, there is a .44 probability that the missile will have no more vertical error than the target dimension, and a .44 probability that it will have no more horizontal error than the target dimension. In order to hit the target, both errors must correspond with the target dimensions at the same time, so the P_h is the product of the two, or approximately .19. The SSP_k then becomes (.19)(.50), which equals about .1.

If .10 kill probability is unacceptable, the munition designer may have to choose a better aimpoint or attack profile, make a more accurate missile, a more lethal kill mechanism, or some combination of all of the

above. In this example, we will investigate adding a warhead fragmentation kill mechanism to the munition. This may increase the SSP_k because fragments may impact the target, even though the missile itself may miss the presented target area. At this point, however, proper analysis requires the definition of several more munition parameters. For this simplified example, at least six: 1) the number of fragments; 2) fragment speed; 3) fragment direction with respect to the missile axis; 4) the warhead burst distance from the target surface (proximity fuze); 5) the missile-target closing velocity at burst; and 6) the fragment lethality given a hit. The first five parameters will affect the P_h of the fragments and the sixth defines the $P_{k/h}$ of each fragment.

For this example, we will use 25 discrete fragments, evenly distributed about the warhead circumference in one fragment ring. The speed of each fragment will be 1000 meters/sec and they travel radially outward due to the explosive force of the warhead. The proximity fuze detonates the warhead at 10 feet from the target. The missile-target closing velocity is 800 meters/sec along a line parallel with an aimpoint at the center of the target area. The probability of any one fragment killing the target is .50. The missile CEP remains the same at 10 feet.

Assessing the added lethality of the warhead due to fragmentation may be performed as follows. Figure 2.2 shows the encounter geometry from a side-on perspective. One sees that the missile-target closing velocity is added to the fragment velocity resulting in a fragmentation cone angle. Given the 10 feet burst point, the fragments will reach this target surface at a radius of 12.5 feet from the aimpoint. Figure 2.3 shows the geometry from the head-on view of the target aimpoint. Clearly, if the missile was to fly precisely to the aimpoint, none of the fragments would intersect the target. However, because of the missile CEP, this will rarely occur.

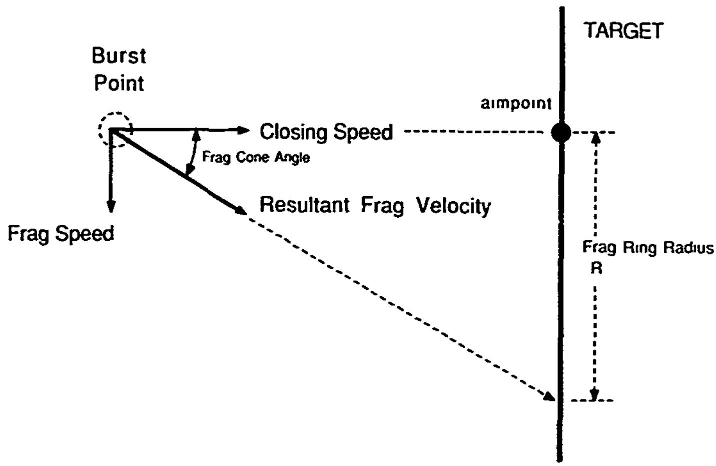


Figure 2.2 - Encounter Geometry from Side-on Perspective

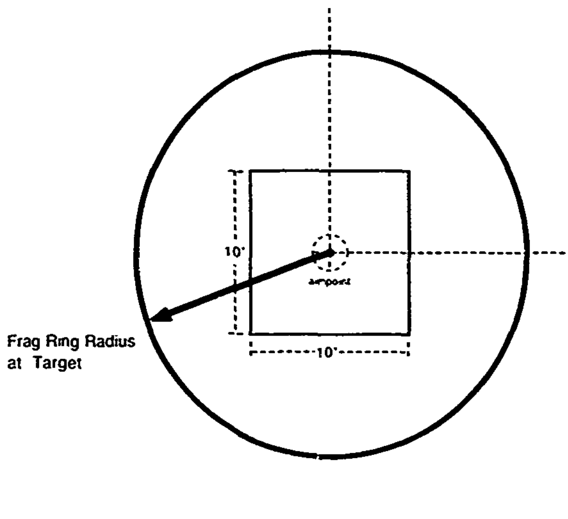
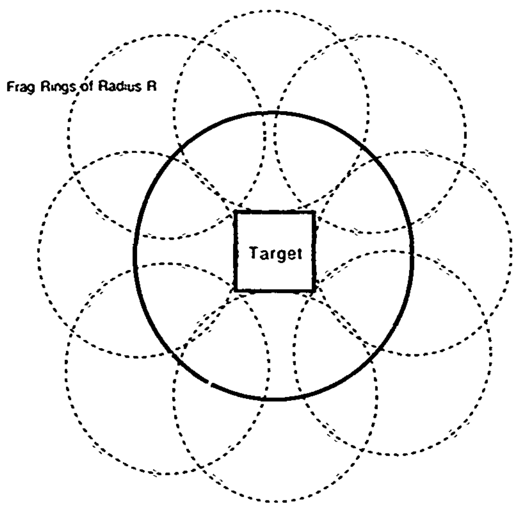


Figure 2.3 - Encounter Geometry from Head-on View

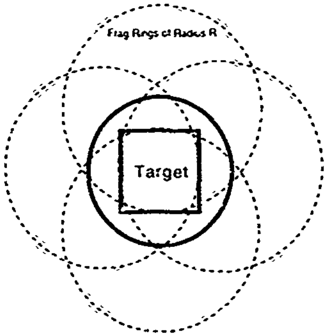
By displacing the expected fragment pattern about the outer perimeter of the target surface, as shown in Figure 2.4, an outer miss distance locus of burst points becomes apparent, for which a portion of the fragment pattern will intersect the target surface. Similarly, as shown in Figure 2.5, an inner locus of burst points exists as well. In Figure 2.6, the two limits for burst locations which result in fragment hits on the target surface are superimposed on the target area and aimpoint. The difference between the outer and inner limits is the burst zone, in which the missile must explode to ensure a probability of a fragment hitting this presented surface. Evaluating the CEP probability distributions allows the probability of a fragment ring hit to be calculated, as shown in Figure 2.7. In this example, the outer radius of the hit zone is 17.5 feet, and the inner radius is 7.5 feet about the aimpoint. These burst limits correspond to 2.0σ and $.88\sigma$, respectively. The probability of the missile bursting within these limits, in both the horizontal and vertical directions, calculates as approximately .11.

This value, however, only predicts the intersection of the fragmentation pattern with this target surface, and not the intersection of any particular fragment with the target. The density of fragments in the pattern, therefore, must be

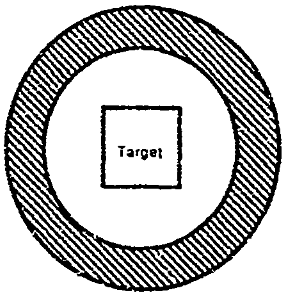


Outer Locus of Burst Points for Frag Hits

Figure 2.4



Inner Locus of Burst Points for Frag Hits
Figure 2.5



Burst Zone for Fragment Ring Hits
Figure 2.6

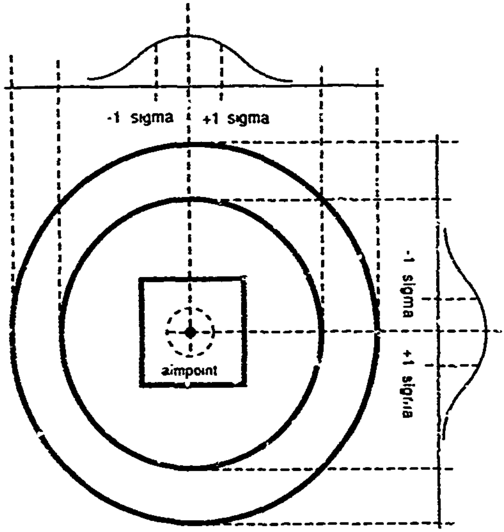
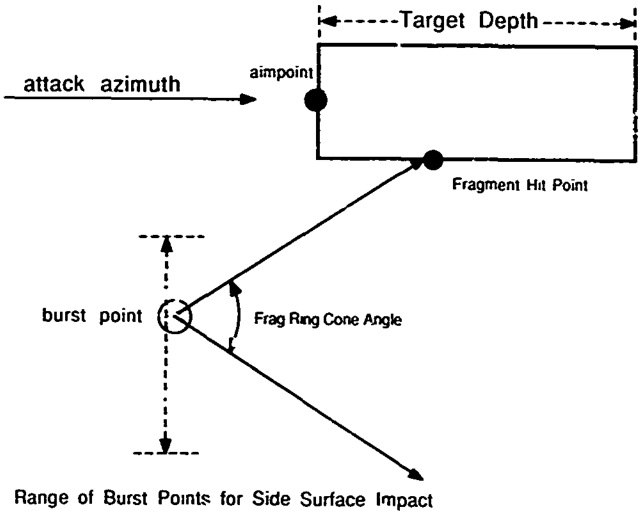


Figure 2.7
Probability Zones for Fragment Hits

considered, as well. With 25 evenly distributed fragments, and a fragment pattern radius of 12.5 feet, there results a fragment linear density of approximately .32 fragments per foot about the perimeter of the ring. Considering that the average linear dimension of the target is 10 feet, one may expect an average of $.32 \times 10 = 3.2$ fragments to hit the target area in any one encounter which results in a fragment pattern intersection. Applying the well known survival rule for multiple probable hits results in a calculated SSP_k for the fragments against this target surface of $(.11)(1-.50^2) = .10$.

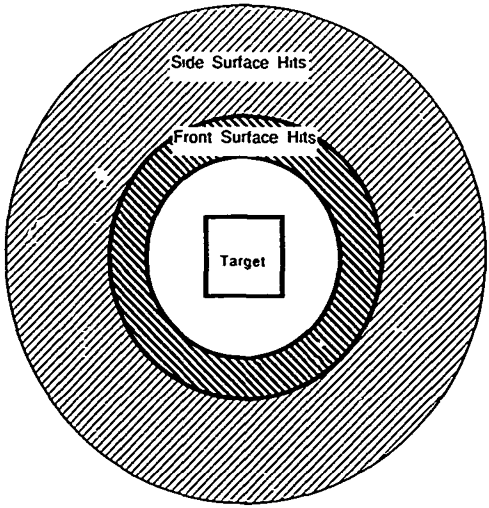
The target surface which has been aimed at, however, is not the only target surface which may be impacted by the fragmentation ring. Figure 2.8 shows a subtle effect of the fragmentation cone angle not previously considered, and not required to be considered when assessing axial warhead kill mechanisms. In Figure 2.8 we see that if the warhead bursts

even further away from the aimpoint than the outer locus of burst points previously indicated in order to achieve a hit on the aimpoint surface, alternate surfaces of the target may be hit. In particular, the target sides, top, and bottom are also vulnerable to the fragmentation pattern. The degree to which these surfaces are vulnerable depends on the depth of the target under attack. Figure 2.9 shows this expanded burst zone which will result in a side surface hit.



Effect of Target Depth on Fragment Ring Hit Probability

Figure 2.8



Burst Zone for Fragment Ring Hits

Figure 2.9

This preliminary analysis of a simplified target example has shown that consideration of fragmentation warheads requires the tradeoff of additional system parameters not required when modeling only an axial warhead kill mechanism, and that the analysis is considerably more detailed containing subtleties not readily apparent to casual observation. Nevertheless, the preliminary methodology presented here clearly forms the basis for expanding the statistical analysis of the effects of changing attack azimuth and elevation on the lethality of warhead axial and fragmentation kill mechanisms, as well as offering the inclusion of the effects of warhead blast on target vulnerability.

3. TARGET GEOMETRY MODELING REQUIREMENT

For the purposes of this research, the development of a simplified yet reliable target geometrical model, which accounts for vulnerable components and their locations within the target, must consider the fact that this model is for use in tradeoff analysis of the lethality of a conceptual or developmental warhead, as opposed to assessing the vulnerability of the intended target. It is true that lethality and vulnerability analyses both require an attacking munition and a target, and the target requires some level of geometrical definition for both cases. However, the level of detail in the target geometry necessary for reliable munition lethality tradeoff analysis may be drastically reduced from the level of detail necessary for reliable target vulnerability analysis.

In target vulnerability analysis, interest is in assessing the vulnerability of as many internal components as possible to any one munition engagement geometry. Therefore, although the target may suffer multiple mobility, firepower, or catastrophic kills as a result of the simultaneous destruction of numerous internal components, it is the knowledge of which components that were destroyed that is of most value to the vulnerability analyst. This knowledge allows design modifications of the vehicle to be performed in an intelligent, informed manner. Therefore, there is an inherent requirement for extreme target detail.

On the other hand, for munition lethality analysis, the target may receive mobility, firepower, or catastrophic kills just the same, but the knowledge of which internal components were simultaneous destroyed, each of which would lead to the same kill assessment if destroyed independently, may be of little concern to the analyst. As long as one of these vulnerable components was destroyed, the lethality assessment is fundamentally the same. Therefore, in lethality modeling, many relatively minutely detailed internal target components can be disregarded, and component geometries can be greatly simplified without the loss of reliable lethality assessment.

It is, of course, fair to say that a target geometry developed for vulnerability analysis will be just as reliable for lethality analysis.

However, the computational expense to exercise these extremely detailed target models may be prohibitive and available to few munition designers during the critical phase of warhead parametric tradeoff analysis. A reliable alternative is, therefore, warranted for the purposes of munition lethality assessment.

What is required to answer these questions is a systematic investigate of the level of target geometry definition required to maintain reliability in the munition lethality assessment. The best way to accomplish this is to begin by defining the model in terms of its major generic classes of vulnerable components, such as the engine, crew, power train, ordnance, fuel cells, and major structural components with course geometrical shapes such as cubes and bricks. The model should then be exercised with several different munition configurations and the results recorded. Subsequently, the target geometry should be refined to progressively greater detail by adding more components of lesser significance and by refining the geometrical shapes of the major components previously identified. After each iteration, the difference in assessed munition lethality should change by ever smaller amounts, until deemed insignificant. At this point we should have a very good understanding of the required level of target definition. A reasonable objective should be to reach a level of detail which results in a change in results that is less than .01 SSP_k (single shot Pk) between subsequent iterations. One may also consider a .025 change as adequate, if achieving greater accuracy adversely affects the simplicity and ease of generating the target geometry.

4. COMPUTER CODE DEVELOPMENT

A computer code was written, which incorporated the necessary mathematical algorithms, subroutines, data input and output formats, target model generation processor, and associated graphics routines that are the functional essence of the lethality model. The initial version of this code does not have all the bells and whistles of fully user friendly final product, since these ancillary tasks are significantly more time consuming and perhaps irrelevant at this point in the model development. It was considered more important to have a basic functional model, which demonstrates its simplicity and performance. The programming language used is Fortran, and the computer software is compatible with IBM AT, 286, 386 and higher machines, although its execution time is significantly different between machines.

5. SOME EXAMPLE CALCULATIONS

The following warhead and munition parameters were used to make some example lethality runs.

Table 5.1
Example Munition Parameters

No. of Radial Fragments	40
Fragment $P_{k/h}$	1
No. of Axial Penetrators	1
Penetrator $P_{k/h}$	1
Missile Velocity	1000 fps
Fragment Velocity	4000 fps

Of primary interest is the lethality variation due to tradeoffs in the number of fragments, fragment velocity, and missile velocity, of which there are many possible combinations. This example simply shows one. In addition, this simplified example shows that all of the fragments fly radially from the axis of the munition. This is not a strict requirement, however. The additional variable of fragment fly-off angle is also available in the model and allows the fragmentation pattern to be defined in terms of multiple rings, each with their own velocity and direction

A. A Generic Helicopter with 5 Vulnerable Components

Figure 5.1 shows the side view of a simple geometric model of a generic helicopter. Five vulnerable components are defined about the centroid of the target area. These components are the gunner, pilot, fuel tank, engine, and transmission. The encompassing outer box surrounding these vulnerable components defines one of several possible warhead fuzing options. If an impact fuze is being modeled, this box could be sized to represent the helicopter skin, which will trigger the warhead. Alternatively, if the warhead uses a proximity fuze, this box could be sized to represent the detonation standoff for a particular proximity fuze. In either case, the fragmentation pattern begins to expand from this outer box.

The lethality assumption of the warhead fragments and axial penetrator is that a hit on any one of these components causes a kill. Therefore, the $P_{k/h}$ is 1. This value, of course, could be made a variable, depending on the component in question, and the attack azimuth and elevation, which would account for any armor or component masking which would shield the component from direct attack. However, for the purposes of this phase of code development, the number of parametric variations is greatly simplified, and serves to demonstrate the utility of the hit probability methodology developed earlier. Figure 5.2 shows a head-on view of the helicopter, and Figure 5.3 shows and oblique attack direction, 10 degrees to the right in azimuth and 20 degrees up in elevation.

Figure 5.1
Profile View of Generic Helicopter Geometry

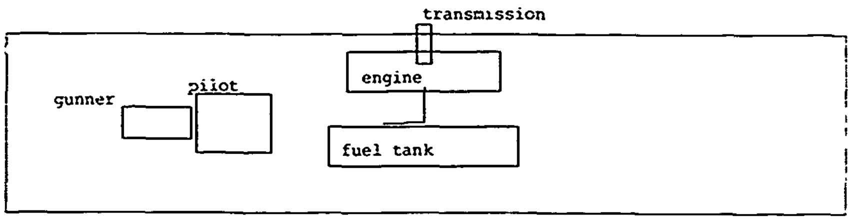


Figure 5.2
Head-On View of Generic Helicopter Geometry

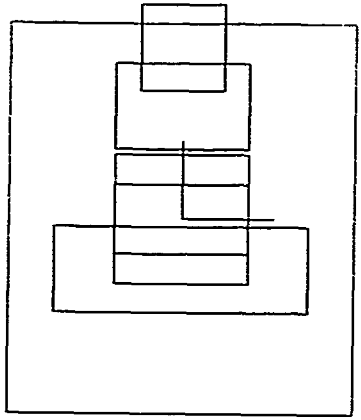


Figure 5.3
Oblique View of Generic Helicopter Geometry
(10 Deg Azimuth and 20 Deg Elevation)

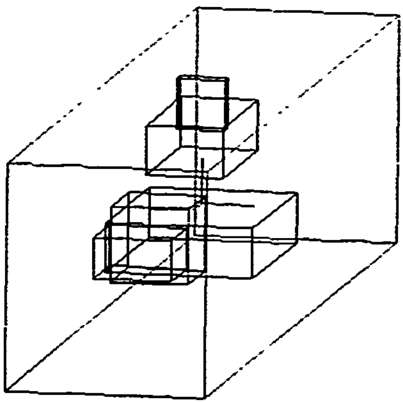


Table 5.2 presents the geometry layout of the target and the resulting single shot Pk for various missile impact errors. To determine these values, the computer code cycles through many discrete attack azimuths and elevations, determining the hit probabilities at each depending on the presented areas for each component. For this example, the attack azimuth was varied from 0 to 180 degrees in steps of 30 degrees, and the attack elevation was varied from 45 degrees above the horizontal to 45 degrees below the horizontal at 15 degree intervals. In all, 36 discrete profiles were evaluated, and the results statistically summed to give an average for all attack elevations and azimuths, as shown in Table 5.2.

Table 5.2
Lethality Results for a 5 Component Target

```
AIM POINT FROM CENTROID OF TARGET (X,Y,Z)
    .00      .00      .00

HIND-D HELICOPTER
LENGTH, WIDTH, HEIGHT
  40.00     7.50    10.00
NUMBER OF CRITICAL COMPONENTS
5
NAME
LENGTH, WIDTH, HEIGHT
CENTROID FROM TARGET CENTROID (X,Y,Z)

PILOT
   3.60     2.90     3.30
   9.10      .00      .00

GUNNER
   3.30     2.90     1.80
  12.80      .00      .00

ENGINE
   7.30     2.90     2.20
    .00      .00     2.90

FUEL TANK
   9.10     5.50     2.20
    .00      .00    -1.30

TRANSMISSION
    .70     1.80     2.20
    .00      .00     4.40
```

```
    I      CEP FT        PKSS
AXIAL WARHEAD
    1       1.0          .812
    2       3.0          .628
    3       5.0          .399
    4       7.0          .261

END OF AXIAL RUN

    I      CEP FT        PKSS
RADIAL FRAGS
    1       1.0          .813
    2       3.0          .721
    3       5.0          .643
    4       7.0          .543

END OF FRAG RUN
END OF RUN
```

The lethality results for this example show that both the warhead axial penetrator and fragmentation case provide high kill probability when the missile has a very small impact error. (Aim point was the centroid of the target, although this too can be varied in the model.) However, as the munition becomes less accurate, the utility of the warhead fragments quickly becomes apparent.

B. A Generic Helicopter with 4 Vulnerable Components

To test the sensitivity of this methodology to the number of target components, the same lethality analysis was performed with one less component in the model. In this case, the helicopter transmission was deleted. Table 5.3 gives the lethality results.

Table 5.3
Lethality Results for a 4 Component Target

```
AIM POINT FROM CENTROID OF TARGET (X,Y,Z)
    .00      .00      .00

HIND-D HELICOPTER
LENGTH, WIDTH, HEIGHT
  40.00     7.50    10.00
NUMBER OF CRITICAL COMPONENTS
4
NAME
LENGTH, WIDTH, HEIGHT
CENTROID FROM TARGET CENTROID (X,Y,Z)

PILOT
   3.60     2.90     3.30
   9.10      .00      .00

GUNNER
   3.30     2.90     1.80
  12.80      .00      .00

ENGINE
   7.30     2.90     2.20
    .00      .00     2.90

FUEL TANK
   9.10     5.50     2.20
    .00      .00    -1.30
```

```
  I      CEP FT        PKSS
AXIAL WARHEAD
  1       1.0          .811
  2       3.0          .617
  3       5.0          .387
  4       7.0          .251

END OF AXIAL RUN

  I      CEP FT        PKSS
RADIAL FRAGS
  1       1.0          .812
  2       3.0          .718
  3       5.0          .640
  4       7.0          .539

END OF FRAG RUN
END OF RUN
```

One sees from these results that the omission of the helicopter transmission from the analysis has little effect on the overall kill probability numbers, and indicates that the addition of a sixth vulnerable component is probably not necessary for these munition parameters.

C. A Generic Helicopter with 3 Vulnerable Components

The model was exercised with a 3 component target, as well. In this case the fuel tank was deleted. Table 5.4 shows the lethality results under these circumstances.

Table 5.4
Lethality Results for a 3 Component Target

```
AIM POINT FROM CENTROID OF TARGET (X,Y,Z)
    .00     .00     .00

HIND-D HELICOPTER
LENGTH, WIDTH, HEIGHT
  40.00    7.50    10.00
NUMBER OF CRITICAL COMPONENTS
3
NAME
LENGTH, WIDTH, HEIGHT
CENTROID FROM TARGET CENTROID (X,Y,Z)

PILOT
    3.60    2.90    3.30
    9.10     .00     .00

GUNNER
    3.30    2.90    1.80
   12.80     .00     .00

ENGINE
    7.30    2.90    2.20
     .00     .00    2.90
```

I	CEP FT	PKSS
AXIAL WARHEAD		
1	1.0	.364
2	3.0	.285
3	5.0	.183
4	7.0	.124

END OF AXIAL RUN

I	CEP FT	PKSS
RADIAL FRAGS		
1	1.0	.681
2	3.0	.506
3	5.0	.413
4	7.0	.331

END OF FRAG RUN
END OF RUN

Clearly, this level of target detail is too course, and in this example, a five component model should be used to develop parametric tradeoffs for any candidate warhead and missile system.

6. SUMMARY AND CONCLUSIONS

The discussion and example calculations presented in this report demonstrate a valid framework and the utility of the fragment hit probability methodology presented earlier, as well as the ability to model traditional axial penetrator components of munition warheads. In addition, further refinement of the computer code, with incorporation of individual component vulnerability differences and issues of component masking, will permit munition designers to quickly tradeoff many competing munition and warhead parameters, in order to develop the most cost effective system, early in the design phase. The methodology presented here also opens the possibility, through imaginative interpretation of the input parameters and target geometry, of evaluating warhead blast lethality. Finally, the model is structured to allow lethality calculations to be performed against many different target types, in addition to aircraft. These additional targets include ground vehicles, buildings, ships, and individual and groups of personnel, which can be similarly modeled solely on the basis of the geometric location of their vulnerable components with respect to the many munition attack directions.